Jet Propulsion Laboratory
California Institute of Technology

The ASTERIA Extended Mission: Results from the Past Year

Lorraine M. Fesq, ASTERIA Program/Project Manager
Jet Propulsion Laboratory, California Institute of Technology.

IEEE Aerospace Conference, Big Sky, MT

March 6, 2019

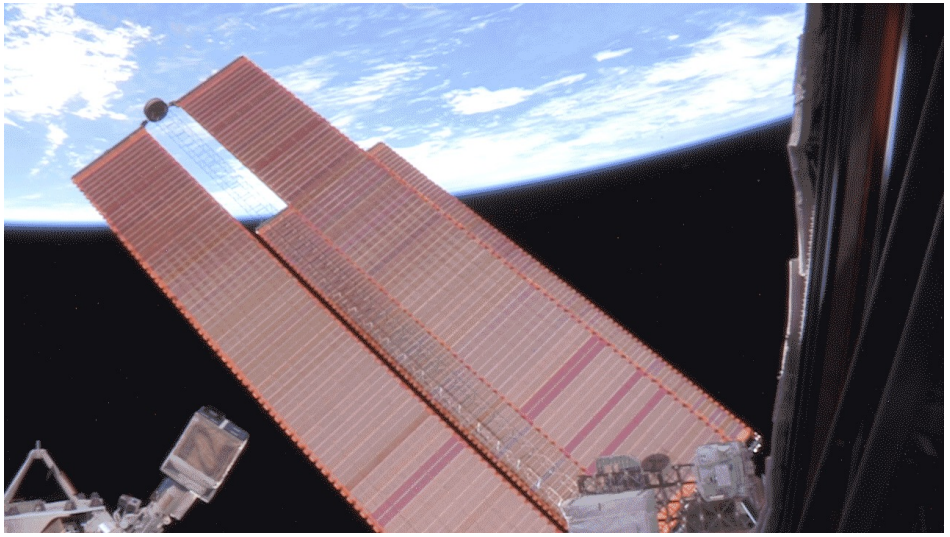
- ASTERIA

Jet Propulsion Laboratory
California Institute of Technology

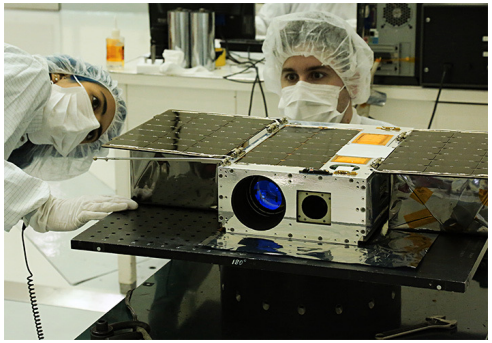
Using the ASTERIA* Cubesat to demonstrate In-Space Autonomy

*Arcsecond Space Telescope Enabling Research In Astrophysics

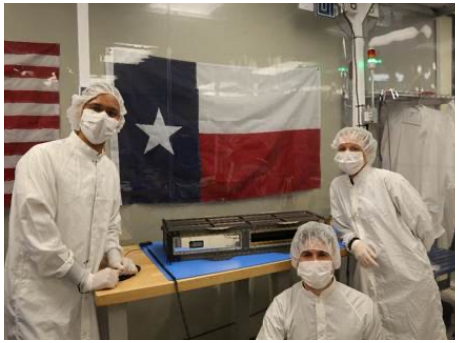
- 6U CubeSat built, tested, operated by JPL
- Collaboration with MIT's Sara Seager, PI
- Demonstrated **pointing stability of <0.5 arcseconds RMS** over 20 minutes
- Demonstrated focal plane **thermal stability of ±0.01 K** over 20 minutes
- **First CubeSat to detect an exoplanet!**



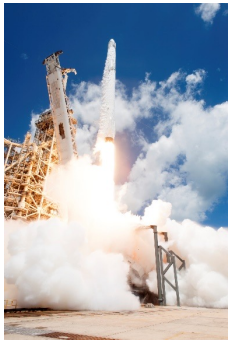
Deployed from International Space Station



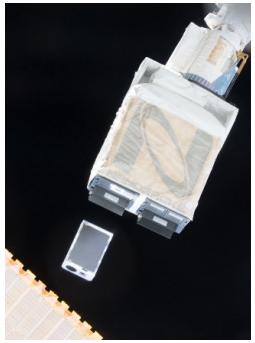
Development
Dec 2014 through Jun 2017



Delivery
1 Jun 2017



Launch
14 Aug 2017



Deployment
20 Nov 2017

Operations lifetime
Exp. through Apr 2020

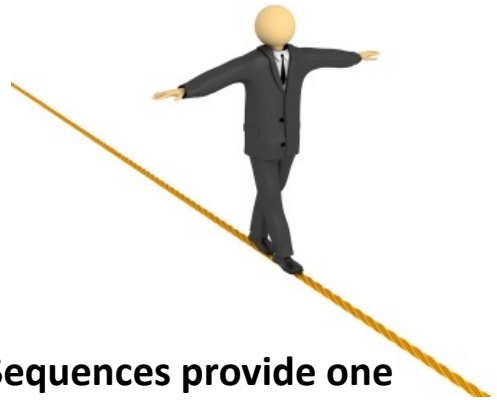
Completed prime mission Feb. 2018; now used for <u>five</u> experiments

ASTERIA Experiment #1. Multi-mission EXECutive (MEXEC) Closed-Loop Task Execution

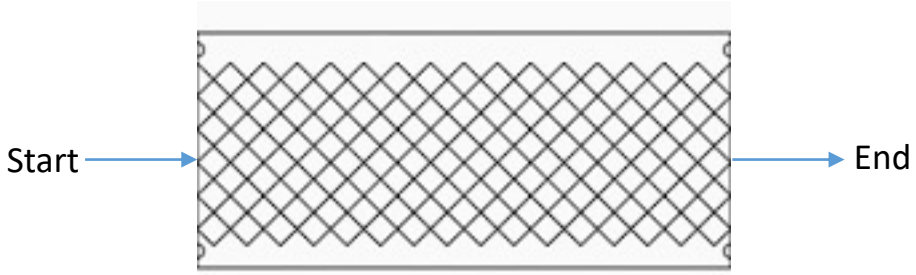
Jet Propulsion Laboratory
California Institute of Technology

Shift the paradigm to operate spacecraft from timed sequences to closed-loop task execution.

- Goal: Demonstrate effectiveness of "task networks" (tasknets) and to increase efficiency and robustness of future space missions
- Tasknets
  - Check preconditions and postconditions of tasks
  - Simpler commanding – WHAT not HOW
  - Reduces down-time on space vehicle
  - Robust on-board execution - space vehicle determines order and timing of activities based on current conditions and handles unexpected events



Sequences provide one execution path

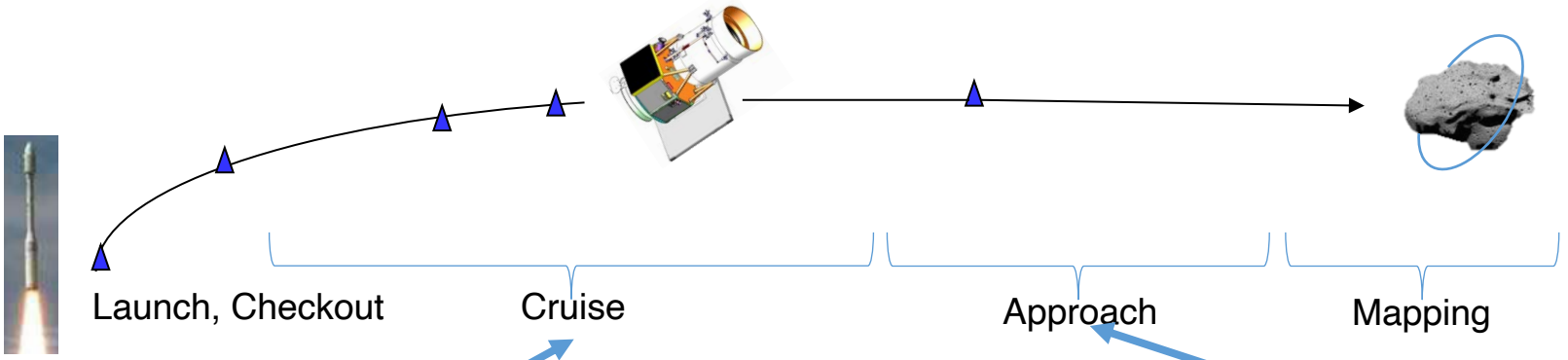


Tasknets provide flexibility to achieve activities

MEXEC code is being flight-certified, integrated into ASTERIA FSW, validated on testbed and uplinked in August 2019.

#2. Autonomous Navigation (AutoNav) Overview

- Optical images of objects are used to estimate spacecraft position, velocity, and attitude
- AutoNav: All ground-based Optical Navigation techniques transferred to spacecraft and automated
- Involves 3 steps
  1. Image processing: Automatically identifies stars or target body in camera FOV and performs center-finding
  2. Orbit determination (OD): Filter combines images and other spacecraft information such as thrusting, attitude knowledge, etc. to determine complete spacecraft position state
  3. Maneuver planning and execution: Maneuvers computed at pre-specified times to retarget s/c to reference trajectory

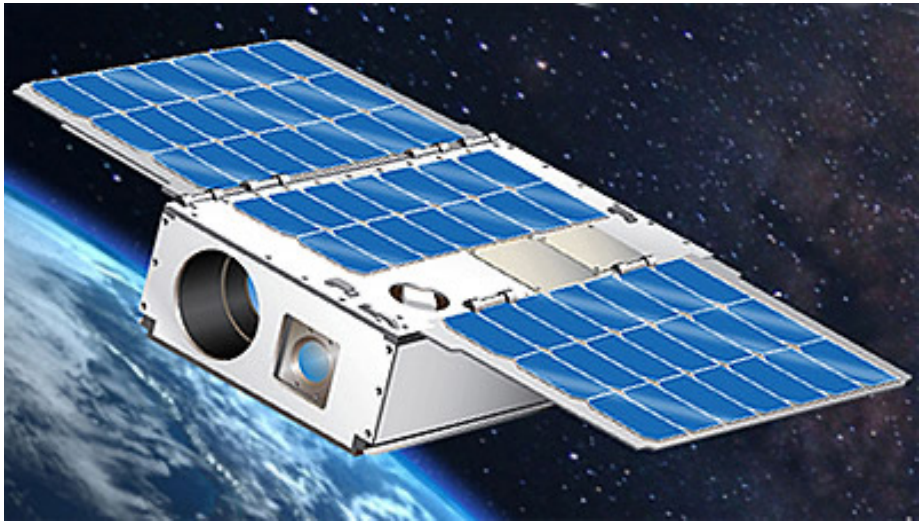


Adapted from a slide by S. Bhaskaran

Jet Propulsion Laboratory
California Institute of Technology

ASTERIA Experiment #3. Autonav

Demonstrate onboard orbit determination in Low Earth Orbit (LEO) without GPS using Autonav.



- Demonstrate a fully independent means of spacecraft OD for Earth orbiters with only passive imaging using ASTERIA camera.
- Enable future missions to navigate in GPS-denied environments.
- Approach:
  - ✓Image a small body to confirm camera quality
  - ✓Image geo-stationary spacecraft to assess feasibility
  - ✓Run Autonav software on testbed for metrics
  - ○ Integrate Autonav into ASTERIA FSW, test and upload.

JPL's Autonav software is being integrated into ASTERIA FSW, validated on testbed and uplinked in late Summer 2019.

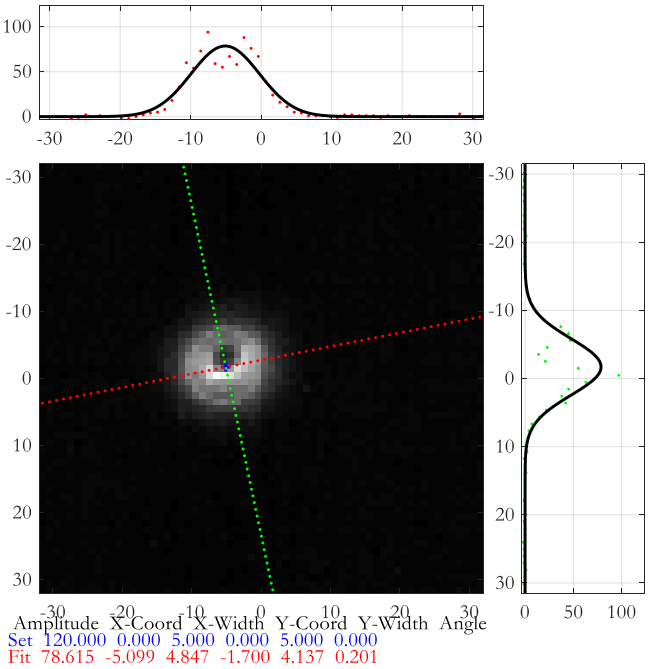
#4 Jitter Experiments

Jet Propulsion Laboratory
California Institute of Technology

Jitter comes in two forms

- **Spacecraft-level jitter**: Flight-validate the JPL's Small Satellite Dynamics Testbed simulation models for the ASTERIA XACT box (ACS system) by running wheels at 4-6 speeds and quantifying image motion. Only uses XACT box for control.
- **Instrument-level jitter**: Uses full instrument control loop (XACT + piezo-stage that moves detector based on optical feedback) to Characterize jitter as a function of RW speeds to better interpret science data.

1000 rpm; Image 1, Window 1 on 2018-11-07



Completed Spacecraft-level jitter characterization

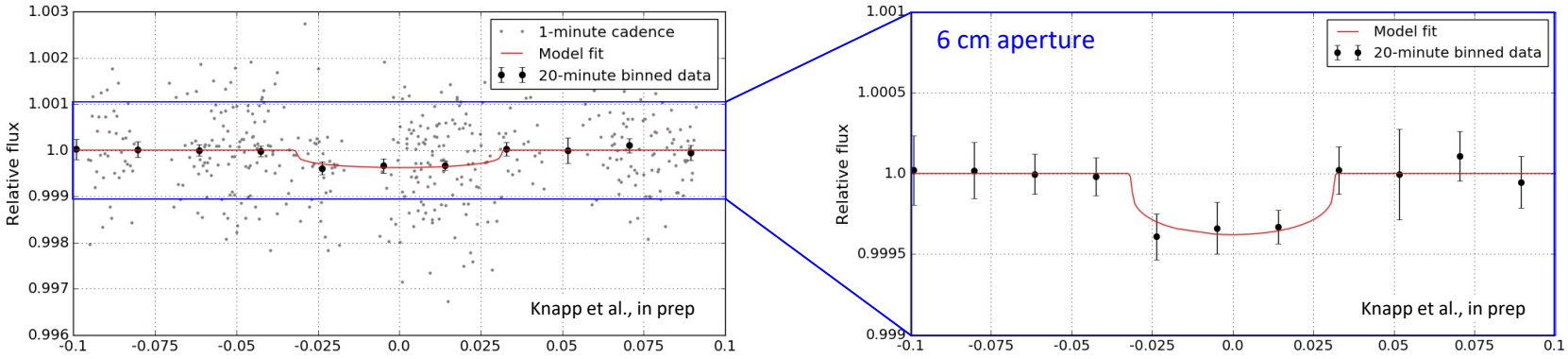
Will benefit future smallsat missions using the XACT box and is crucial to astrophysics smallsat missions (improves science data quality)

Jet Propulsion Laboratory
California Institute of Technology

#4. Science Observations

Perform new ASTERIA observations to extend mission science.

- ASTERIA has demonstrated unprecedented photometric precision for a CubeSat mission.
- Current science goals will **shift from follow-up of previously detected planets to discovery of as-yet unknown additional planets**. The spacecraft is uniquely suited to perform long-term monitoring of stars such as alpha Centauri for small transiting planets.
- **The discovery of a transiting Earth-sized planet around alpha Cen A and/or B would be of the highest scientific value** as such a planet would be our closest exoplanetary neighbor orbiting a Sun-like star.



Observed known transit of 55 Cancri e transit

Back-up

#5. Amazon Web Services Ground Station Experiment

Amazon Web Services (AWS) Ground Station (GS) locks onto ASTERIA - its first NASA Spacecraft!

- "Amazon Ground Station as a Service*" announced in Fall 2018
- **At the request of NASA HQ/ESTO**, ASTERIA conducted downlink experiment in January 2019 with an AWS GS
  - AWS GS "listened" while ASTERIA performed regular downlink operations with Morehead State University ground station.
  - AWS GS was able to lock onto the transmitted signal - achieved carrier lock and frame sync
- Planning experiment to demonstrate uplink and downlink (pending NTIA license update)
- Significant step to evaluate potential for future CubeSat missions to use AWS GSs
  - Potential to increase telecom options
  - Provide more flexibility in operations
  - Reduce costs – pay-by-minute model

This experiment will benefit future CubeSats, confirming that AWS GS can provide communication services

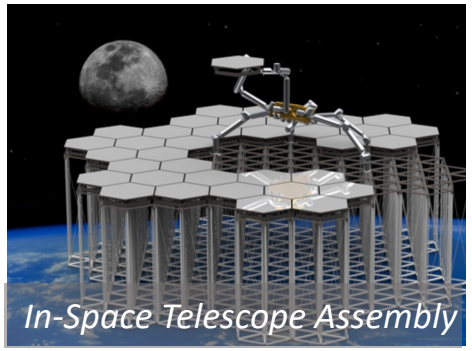
*https://aws.amazon.com/ground-station/

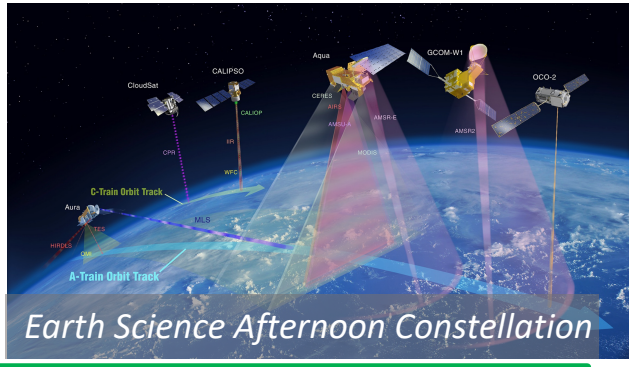
Jet Propulsion Laboratory
California Institute of Technology

Summary

- ASTERIA is an ideal platform for experiments
  - Two years remained life past prime mission
  - Flight software is changeable
  - Highly capable spacecraft and payload
- Five experiments being conducted on ASTERIA
  1. Exoplanet exploration
  2. Task-level execution
  3. Autonav for LEO w/o GPS
  4. Jitter Characterization
  5. NASA HQ/ESTO AWS Ground Station testing
- Additional experiments in the pipeline
  - *NASA HQ/ESTO Sensor-Web*
  - *Model-based health assessment*
- These capabilities are relevant to planetary, astrophysics and Earth Sciences


Mars Ascent Vehicle


In-Space Telescope Assembly



Earth Science Afternoon Constellation

ASTERIA is a role model for using in-space assets to mature technologies and cross the TRL "valley of death." LET'S USE MORE ASSETS FOR MORE EXPERIMENTS!

Jet Propulsion Laboratory
California Institute of Technology

Acknowledgements

- **Co-authors:**
  - **JPL**: Patricia Beauchamp, Amanda Donner, Rob Bocchino, Brian Kennedy, Faiz Mirza, Swati Mohan, David Sternberg, Matthew W. Smith, Martina Troesch
  - **MIT Haystack Observatory**: Mary Knapp
- **We Thank**
  - ASTERIA Principal Investigator Sara Seager (MIT) for supporting our efforts to use the spacecraft for these technology demonstrations while continuing to perform exoplanet exploration science;
  - The JPL ASTERIA team: Brian Barker, Brian Campuzano, Peter DiPasquale, Kyle Hughes, Ansel Rothstein-Dowden, Jose Carlos Abesmis, Jules Lee, and Kristine Fong, who continue to keep the spacecraft healthy and operational;
  - Chris Pong, Shyam Bhaskaran, Patrick Doran, David Ardila, Aadil Rizvi, Tomas Martin-Mur, Professor Soon-Jo Chung (Caltech) and Carolyn Maynard (Raytheon) who are supporting development of the technology demonstrations;
  - Bryce Demory (University of Bern) for science data analysis;
  - Ben Malphrus and his team from Morehead State University for continued ground station support.